A new N^* resonance as a hadronic molecular state

Daisuke Jido[1;1)]   Yoshiko Kanada-En'yo[1]

1 (Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan)

Abstract We report our recent work on a hadronic molecule state of the $K\bar{K}N$ system with $I = 1/2$ and $J^P = 1/2^+$. We assume that the $\Lambda(1405)$ resonance and the scalar mesons, $f_0(980)$, $a_0(980)$, are reproduced as quasi-bound states of $\bar{K}N$ and $K\bar{K}$, respectively. Performing non-relativistic three-body calculations with a variational method for this system, we find a quasibound state of the $K\bar{K}N$ system around 1910 MeV below the three-body breakup threshold. This state corresponds to a new baryon resonance of N^* with $J^P = 1/2^+$. We find also that this resonance has the cluster structure of the two-body bound states keeping their properties as in the isolated two-particle systems. We also briefly discuss another hadronic molecular state composed by two $\bar{K}$ and one N, which corresponds to a Ξ^* resonance.

Key words three-body bound state, $\Lambda(1405)$ resonance, kaon-nucleon interaction, variational calculation

PACS 14.20.Gk, 13.75.Jz, 13.30.Eg, 21.45.-v

1 Introduction

The structure of baryon resonances has been investigated in quark models, in which symmetries of constituent quarks, such as spin, flavor and color, and their radial excitations play a major role to describe the wavefunctions of the baryon resonances. Since the baryon resonances decay into low-lying mesons and a baryon with the strong interactions, the resonances may have also large components of mesons and baryons. For these components, inter-hadron dynamics is important and gives essential contributions to understand the structure of the baryon resonances.
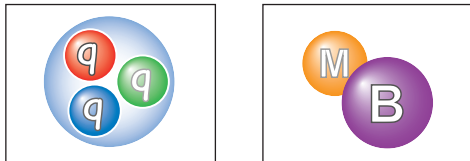

Fig. 1.   Schematic pictures of baryon resonances.

These two pictures are complementary, and which picture is realized in a baryon resonance depends on the energy scale to see the resonance, since the interaction ranges are different in these pictures. Nevertheless, for some baryon resonances, the quark core components are not significant and the resonances are predominantly composed by hadrons. In such resonances, the quarks are clustered and their dynamics are confined inside the constituent hadrons.

One of the historical examples is the $\Lambda(1405)$ resonance having $S = -1$ and $J^p = (1/2)^-$, which has been considered as a quasibound state of the $\bar{K}N$ system [1]. Modern calculations based on chiral dynamics with unitary coupled-channels formulations also reproduce the $\Lambda(1405)$ as a dynamically generated resonance in meson-baryon scattering with $S = -1$ and $I = 0$ [2, 3, 4, 5, 6, 7, 8]. A recent investigation [9] pointed out that the $\Lambda(1405)$ can be regarded almost purely as a dynamically generated state in meson-baryon scattering, while the description of the $N(1535)$ demands some components other than meson-baryon ones, such as genuine quark components. It has been also suggested that the $f_0(980)$ and $a_0(980)$ scalar mesons are molecular states of $K\bar{K}$ [10]. The strong attraction in the $\bar{K}N$ system led to the idea of deeply bound kaonic states in light nuclei, such as K^-pp and K^-ppn, pointed out in Ref. [11]. Later, many theoretical studies on the structure of the K^-pp system have been performed, having turned out that the K^-pp system is bound with a large width [12]. Two mesons and one baryon systems have been also investigated [13, 14, 15, 16, 17], and one of their findings is that a quasibound state is formed in the $K\bar{K}N$ system around 1910 MeV as an N^* resonance [16, 17].

In such multi-hadron systems, anti-kaon plays a unique role for hadron dynamics due to its heavier mass and Nambu-Goldstone boson nature. According to the chiral effective theory, the $\bar{K}N$ and

$\bar{K}K$ interactions are strongly attractive in the s-wave channel, and, owing to the heavy kaon mass, the s-wave interactions are more effective than those for the pion around the threshold energy. In addition, being aware that the typical kaon kinetic energy in the bound systems estimated by the hadronic interaction range is small in comparison with the kaon mass, one may treat the kaons in multi-hadron systems in non-relativistic potential models done for nucleons in nuclear physics.

Recent achievement of the studies on the s-wave $\bar{K}N$ effective potential is that $\bar{K}N$ interaction with $I = 0$ is strongly attractive and develops a quasibound state somewhere around the $\Lambda(1405)$ resonance. Starting from these strong $\bar{K}N$ interactions together with the $\bar{K}K$ quasibound picture of $f_0(980)$ and $a_0(980)$, we examine possible bound states of the lightest two-kaon nuclear systems $K\bar{K}N$ and $\bar{K}\bar{K}N$ with $I = 1/2$ and $J^P = 1/2^+$, in the hadronic molecule picture. Using a non-relativistic potential model to describe the two-body interactions, we solve the three-body problem in a variational method, and find a new N^* resonance which is not listed in Particle Data Table. The details of the calculation can be found in Refs. [14, 16]. Recently the $K\bar{K}N$ system was studied also in a more sophisticated calculation using the Faddeev formulation and they found a generated resonance at the same energy [17, 18] as our investigation.

2   Formulation

We use a non-relativistic three-body potential model for the $K\bar{K}N$ system. The Hamiltonian for the $K\bar{K}N$ system is given by

$$H = T + V \tag{1}$$
$$V \equiv V_{\bar{K}N}(r_1) + V_{KN}(r_2) + V_{K\bar{K}}(r_3), \tag{2}$$

with the kinetic energy T and the potential energy V which consists of effective two-body interactions given in ℓ-independent local potentials as functions of $\bar{K}$-N, K-N and K-$\bar{K}$ distances. We assume isospin symmetry in the effective interactions, and we also use isospin-averaged masses, $M_K = 495.7$ MeV and $M_N = 938.9$ MeV. We do not consider three-body forces nor transitions to two-hadron decays, which will be important if the constituent hadrons are localized in a small region.

The effective interactions are described in complex-valued functions representing the open channels, $(\pi\Lambda, \pi\Sigma)$ for $\bar{K}N$ and $(\pi\pi, \pi\eta)$ for $K\bar{K}$. In solving Schrödinger equation for the three-body $K\bar{K}N$

system, we first take only the real part of the potentials and obtain the wavefunctions in a variational approach with a Gaussian expansion method developed in Ref. [19]. With the wavefunctions, we calculate the bound state energies E as expectation values of the total Hamiltonian (1). The widths of the bound states are evaluated by the imaginary part of the complex energies as $\Gamma = -2\,\mathrm{Im}E$.

The effective interactions are parametrized in a one-ragne Gaussian form as

$$V_a(r) = U_a \exp\left[-(r/b)^2\right] \tag{3}$$

with the potential strength U and the range parameter b. The parameters used in this work are summarized in Table 1.

Table 1. Parameters of the effective interactions and properties of two-body systems. The energies (E) are evaluated from the corresponding two-body breakup threshold. We also list the root-mean-square distances of the $\bar{K}N(I = 0)$, $K\bar{K}(I = 0)$ and $K\bar{K}(I = 1)$ states, which correspond to $\Lambda(1405)$ and $f_0(980), a_0(980)$, respectively. For the $K\bar{K}$ interactions, we show the scattering lengths obtained in the present parameter.

	parameter set of interactions	
	(A)	(B)
b (fm)	0.47	0.66
$\bar{K}N$	HW-HNJH	AY
$U_{KN}^{I=0}$ (MeV)	$-908-181i$	$-595-83i$
$U_{KN}^{I=1}$ (MeV)	$-415-170i$	$-175-105i$
$\bar{K}N(I=0)$ state		
ReE (MeV)	-11	-31
ImE (MeV)	-22	-20
$\bar{K}$-N distance (fm)	1.9	1.4
$K\bar{K}$	KK(A)	KK(B)
$U_{K\bar{K}}^{I=0,1}$ (MeV)	$-1155-283i$	$-630-210i$
$K\bar{K}(I=0,1)$ state		
ReE (MeV)	-11	-11
ImE (MeV)	-30	-30
K-$\bar{K}$ distance (fm)	2.1	2.2
KN	KN(A)	KN(B)
$U_{KN}^{I=0}$ (MeV)	0	0
$U_{KN}^{I=1}$ (MeV)	820	231
$a_{KN}^{I=0}$ (fm)	0	0
$a_{KN}^{I=1}$ (fm)	-0.31	-0.31

One of the key issues for study of the $\bar{K}N$ in-

teraction is the subthreshold property of the $\bar{K}N$ scattering amplitude, namely the resonance position of $\Lambda(1405)$. Particle Data Group [20] reports the mass of the $\Lambda(1405)$ resonance around 1405 MeV, which is extracted mainly in the $\pi\Sigma$ final state interaction. Based on this fact, a phenomenological effective $\bar{K}N$ potential (AY potential) was derived in Refs. [11, 21], having relatively strong attraction in the $I = 0$ channel to provide the K^-p bound state at 1405 MeV. Recent theoretical studies of $\Lambda(1405)$ in coupled channels approach with chiral dynamics have indicated that $\Lambda(1405)$ is described as a superposition of two pole states and one of the states is considered to be a $\bar{K}N$ quasibound state embedded in strongly interacting $\pi\Sigma$ continuum [8, 9, 22]. This double-pole nature suggests that the resonance position in the $\bar{K}N$ scattering amplitudes with $I = 0$ is around 1420 MeV, which is higher than the energy position of the nominal $\Lambda(1405)$ resonance. This is confirmed by the bubble chamber experiments of the $K^-d \to n\Lambda(1405)$ reaction [23], in which the $\Lambda(1405)$ spectrum has a peak structure clearly at 1420 MeV instead of 1405 MeV. This reaction has been recently investigated in Ref. [24], and it was found that the $\Lambda(1405)$ is produced by the $\bar{K}N$ channel in this reaction. Based on the chiral SU(3) coupled-channel dynamics, Hyodo and Weise have derived another effective $\bar{K}N$ potential (HW potential) [22]. The HW potential provides a $\bar{K}N$ quasibound state at ~ 1420 MeV instead of 1405 MeV, and is not as strong as the AY potential. Here we compare these two different effective potentials. For the HW potential, we use the parameter set referred as HNJH in Ref. [22], which was obtained by the chiral unitary model with the parameters of Ref. [7]. We refer to this potential as "HW-HNJH potential"

For the interactions of the $\bar{K}K$ systems with $I = 0$ and $I = 1$, the strengths $U_{\bar{K}N}$ in Eq. (3) are determined so as to form quasibound states having the observed masses and widths of $f_0(980)$ and $a_0(980)$. We take the mass 980 MeV and the width 60 MeV as the inputs to determine the $K\bar{K}$ interactions in both the $I = 0$ and $I = 1$ channels. In this phenomenological single-channel interaction, the effect of the two-meson decays such as $\pi\pi$ and $\pi\eta$ decays is incorporated in the imaginary part of the effective $K\bar{K}$ interaction. In this model, the $K\bar{K}$ interaction is independent of the total isospin of $K\bar{K}$, because it is adjusted to reproduce the f_0 and a_0 scalar mesons having the same mass and width. The repulsive KN interaction is fixed by experimentally obtained scattering lengths: $a_{KN}^{I=0} = -0.035$ fm and $a_{KN}^{I=1} = -0.310 \pm 0.003$ fm [25].

For the range parameters of the $\bar{K}K$ and KN potentials we use the same values of the $\bar{K}N$ interaction, $b = 0.47$ fm for the HW-HNJH potential and $b = 0.66$ fm for the AY potential. The depths of the attractive potentials shown in Table 1 are compatible with the kaon mass. Nevertheless, the kinetic energies of the kaon in the two-body bound systems are small enough for nonrelativistic treatments of multi-kaon systems. The two-body interactions are schematically summarized in Table 2. Hereafter we refer to the quasibound $\bar{K}N$ and $K\bar{K}$ states as $\{\bar{K}N\}_{I=0}$ and $\{K\bar{K}\}_{I=0,1}$, respectively.

Table 2. Two-body interaction. The quasibound states in the corresponding channels are indicated as the resonances.

	$I = 0$	$I = 1$	threshold
$\bar{K}N$	$\Lambda(1405)$	week attraction	1434.6 MeV
$K\bar{K}$	$f_0(980)$	$a_0(980)$	991.4 MeV
KN	very weak	strong repulsion	1434.6 MeV

3 Results

Let us show the results of the three-body calculation of the $K\bar{K}N$ system with $I = 1/2$ and $J^P = 1/2^+$. As shown in Fig. 2, we find that, in both parameters (A) for HW-HNJH and (B) for AY, a $K\bar{K}N$ bound state is obtained below all of the threshold energies of the $\{\bar{K}N\}_{I=0}+K$, $\{K\bar{K}\}_{I=0}+N$ and $\{K\bar{K}\}_{I=1}+N$ channels, which correspond to the $\Lambda(1405)+K$, $f_0(980)+N$ and $a_0(980)+N$ states, respectively. This means that the obtained bound state is stable against breaking up to the subsystems.
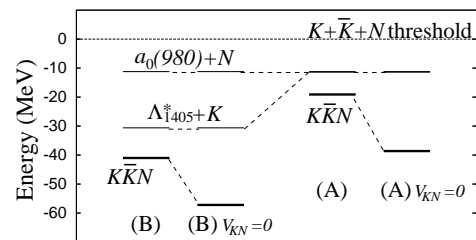

Fig. 2. Level structure of the $K\bar{K}N$ system calculated with (A) the HW-HNJH potential and (B) the AY potential. The energies are measured from the $K+\bar{K}+N$ threshold located at 1930 MeV. The bound state is denoted by $K\bar{K}N$. The calculated thresholds of the two-body decays to $\{K\bar{K}\}_{I=0,1}+N$ and $\{\bar{K}N\}_{I=0}+K$ are denoted by $a_0(980)+N$ and Λ_{1405}^*+K, respectively. The results obtained without the KN repulsion are also shown.

3.1 Energy and width of the $K\bar{K}N$ state

The values of the real and imaginary parts of the obtained energies are given in Table 3. The imaginary part of the energy corresponds to the half width of the quasi-bound state. The contribution of each decay mode is also shown as an expectation value of the imaginary potential $\langle \mathrm{Im}V\rangle$. The binding energies of the $K\bar{K}N$ state measured from the three-body $K+\bar{K}+N$ threshold are found to be -19 MeV and -41 MeV in the cases of (A) and (B), respectively. The difference stems from the fact that the AY potential gives a deeper binding of the $\{\bar{K}N\}_{I=0}$ state than the HW-HNJH potential due to the stronger $\bar{K}N$ attraction. It is more physically important that the $K\bar{K}N$ bound state appears about 10 MeV below the lowest two-body threshold, $\{\bar{K}N\}_{I=0}+K$, in both cases (A) and (B). This energy is compatible to nuclear many-body system, and it is considered to be weak binding energy in the energy scale of hadronic system.

Table 3. Energies of the $K\bar{K}N$ states calculated with parameter (A) and (B) given in Table 1. Contributions of $V_{\bar{K}N}^{I=0,1}$ and $V_{K\bar{K}}^{I=0,1}$ to the imaginary energy are separately listed.

parameter set	(A)	(B)
$V_{\bar{K}N}$	HW-HNJH	AY
$\mathrm{Re}E$	-19	-41
$\langle T\rangle$	169	175
$\langle \mathrm{Re}V\rangle$	-188	-216
$\mathrm{Im}E$	-44	-49
$\langle \mathrm{Im}V_{\bar{K}N}^{I=0}\rangle$	-17	-19
$\langle \mathrm{Im}V_{\bar{K}N}^{I=1}\rangle$	-1	0
$\langle \mathrm{Im}V_{K\bar{K}}^{I=0}\rangle$	-1	-4
$\langle \mathrm{Im}V_{K\bar{K}}^{I=1}\rangle$	-25	-25

The weakly bound system has the following significant feature. Comparing the results of the $K\bar{K}N$ with the properties of the two-body subsystems shown in Table 1, it is found that the obtained binding energies and widths of the $K\bar{K}N$ state are almost given by the sum of those of $\Lambda(1405)$ and $a_0(980)$ (or $f_0(980)$), respectively. This indicates that two subsystems, $\bar{K}N$ and $K\bar{K}$, are as loosely bound in the three-body system as they are in two-body system.

The decay properties of the $K\bar{K}N$ state can be discussed by the components of the imaginary energy. As shown in Table 3, among the total width $\Gamma = -2E^{\mathrm{Im}} \sim 90$ MeV, the components of the $\bar{K}N$ with $I=0$ and the $K\bar{K}$ with $I=1$ give large contributions as about 40 MeV and 50 MeV, respectively.

The former corresponds to the $\Lambda(1405)$ decay to the $\pi\Sigma$ mode with $I=0$, while the latter is given by the $a_0(980)$ decay, which is dominated by $K\bar{K}\to\pi\eta$. In contrast, the $\bar{K}N$ $(I=1)$ and the $K\bar{K}$ $(I=0)$ interactions provide only small contributions to the imaginary energy. This is because, as we will see later, the $\bar{K}N$ subsystem is dominated by the $I=0$ component due to the strong $\bar{K}N$ attraction and the $K\bar{K}$ subsystem largely consists of the $I=1$ component as a result of the three-body dynamics. The small contributions of the $\bar{K}N$ $(I=1)$ and the $K\bar{K}$ $(I=0)$ interactions to the imaginary energy implies that the decays to $\pi\Lambda K$ and $\pi\pi N$ are suppressed. Therefore, we conclude that the dominant decay modes of the $K\bar{K}N$ state are $\pi\Sigma K$ and $\pi\eta N$. This is one of the important characters of the $K\bar{K}N$ bound system.

3.2 Structure of the $K\bar{K}N$ state

For the isospin configuration of the $K\bar{K}N$ state, we find that the $\bar{K}N$ subsystem has a dominant $I=0$ component, as shown in Table 4. In the $K\bar{K}$ subsystem, the $I=1$ configuration is dominant while the $I=0$ component gives minor contribution. This is because, in both $I=0$ and $I=1$ channels, the $K\bar{K}$ attraction is equally strong enough to provide quasi-bound $K\bar{K}$ states, but the $I=1$ configuration of $K\bar{K}$ is favorable to have total isospin $1/2$ for the $K\bar{K}N$ with the $\{\bar{K}N\}_{I=0}$ subsystem. Due to this isospin configuration, the $K\bar{K}N$ system has the significant decay patterns as discussed above.

Table 4. Isospin and spatial structure of the $K\bar{K}N$ state with parameter (A) and (B) given in Table 1. The r.m.s. radius of the K, $\bar{K}$ and N distribution, and the r.m.s. values for the $\bar{K}$-N, K-$\bar{K}$ and K-N distances are listed. The detailed definitions are described in Ref. [16].

	(A)	(B)
	HW-HNJH	AY
isospin configuration		
$\Pi\left(\left[\bar{K}N\right]_0\right)$	0.93	0.99
$\Pi\left(\left[\bar{K}N\right]_1\right)$	0.07	0.01
$\Pi\left(\left[K\bar{K}\right]_0\right)$	0.09	0.17
$\Pi\left(\left[K\bar{K}\right]_1\right)$	0.91	0.83
spatial structure		
$r_{K\bar{K}N}$ (fm)	1.7	1.4
$d_{\bar{K}N}$ (fm)	2.1	1.3
$d_{K\bar{K}}$ (fm)	2.3	2.1
d_{KN} (fm)	2.8	2.3

We discuss the spatial structure of the $K\bar{K}N$ bound system. In Table 4, we show the root-mean-square (r.m.s.) radius of $K\bar{K}N$, $r_{K\bar{K}N}$, and r.m.s. values for the $\bar{K}$-N, K-$\bar{K}$ and K-N distances, $d_{\bar{K}N}$, d_{KN}, $d_{K\bar{K}}$. The definitions are given in Ref. [16]. The r.m.s. distances of the two-body systems, $\{\bar{K}N\}_{I=0}$ and $\{K\bar{K}\}_{I=0,1}$, are shown in Table 1. It is interesting that the present result shows that the r.m.s. $\bar{K}$-N and K-$\bar{K}$ distances in the three-body $K\bar{K}N$ state have values close to those in the quasi-bound two-body states, $\{\bar{K}N\}_{I=0}$ and $\{K\bar{K}\}_{I=0,1}$, respectively. This implies again that the two subsystems of the three-body state have very similar characters with those in the isolated two-particle systems.

Combining the discussions of the isospin and spatial structure of the $K\bar{K}N$ system, we conclude that the structure of the $K\bar{K}N$ state can be understood simultaneous coexistence of $\Lambda(1405)$ and $a_0(980)$ clusters as shown in Fig. 3. This does not mean that the $K\bar{K}N$ system is described as superposition of the $\Lambda(1405) + K$ and $a_0(980) + N$ states, because these states are not orthogonal to each other. The probabilities for the $K\bar{K}N$ system to have these states are 90%. It means that $\bar{K}$ is shared by both $\Lambda(1405)$ and a_0 at the same time.
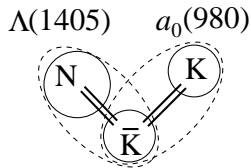
$$\Lambda(1405) \qquad a_0(980)$$

Fig. 3.   Schematic structure of the $K\bar{K}N$ bound system.

It is also interesting to compare the obtained $K\bar{K}N$ state with nuclear systems. As shown in Table 3, the hadron-hadron distances in the $K\bar{K}N$ state are about 2 fm, which is as large as typical nucleon-nucleon distance in nuclei. In particular, in the case (A), the hadron-hadron distances are larger than 2 fm and the r.m.s. radius of the three-body system is also as large as 1.7 fm. This is larger than the r.m.s. radius 1.4 fm of ^{4}He. If we assume uniform sphere density of the three-hadron system with the r.m.s. radius 1.7 fm, the mean hadron density is to be 0.07 hadrons/(fm^3). Thus the $K\bar{K}N$ state has large spatial extent and dilute hadron density.

We discuss the role of the KN repulsion in the $K\bar{K}N$ system. In Ref. [16], we have shown the results calculated without the KN interaction. There it has been found in both (A) and (B) cases that the binding energy of the $K\bar{K}N$ state is 20 MeV larger than the case with the KN repulsion, and that the

widths also becomes larger, $\Gamma = 130 - 140$ MeV. We also obtain spatially smaller three-body system. As a result of the localization, the system can gain more potential energy and larger imaginary energy in the case of no KN interaction than the case with the KN repulsion. In other words, thanks to the KN repulsion, the $K\bar{K}N$ state is weakly bound and its width is suppressed to be as small as the sum of the widths of the subsystems. The distances of the two-body subsystems obtained without the KN interaction are as small as about 1.5 fm, which is comparable with the sum of the charge radii of proton (0.8 fm) and K^+ (0.6 fm). For such a small system, three-body interactions and transitions to two particles could be important. In addition, the present picture that the system is described in nonrelativistic three particles might be broken down, and one would need relativistic treatments and two-body potentials with consideration of internal structures of the constituent hadrons.

Finally we shortly discuss the $\bar{K}\bar{K}N$ system with $S = -2$, $I = 1/2$ and $J^p = (1/2)^+$. For the $\bar{K}\bar{K}N$ system, the binding energy from the $\Lambda(1405)+\bar{K}$ threshold is found to be as small as a few MeV due to the strong repulsion $\bar{K}\bar{K}$ with $I = 1$ [14]. The reason of the small binding energy is understood by isospin configuration of this system. Due to the strong attraction of $\bar{K}N$ with $I = 0$, one of the $\bar{K}N$ pair forms a quasibound $\Lambda(1405)$ state. At the same time, the other pair of $\bar{K}N$ has dominantly $I = 1$ component to have total isospin $1/2$ of the $\bar{K}\bar{K}N$ system. Although the $\bar{K}N$ with $I = 1$ is attractive, the attraction is not enough to overcome the repulsive $\bar{K}\bar{K}$ interaction.

4   Conclusion and discussion

We have investigated the $K\bar{K}N$ system with $J^p = 1/2^+$ and $I = 1/2$ in the non-relativistic three-body calculation under the assumption that $\bar{K}N$ and $K\bar{K}$ systems form quasibound states as $\Lambda(1405)$, $f_0(980)$ and $a_0(980)$. The present three-body calculation suggests a weakly quasibound state below all threshold of the two-body subsyetems. For the structure of the $K\bar{K}N$ system, we have found that the subsystems of $\bar{K}N$ and $K\bar{K}$ are dominated by $I = 0$ and $I = 1$, respectively, and that these subsystems have very similar properties with those in the isolated two-particle systems. This leads that the $K\bar{K}N$ quasi-bound system can be interpreted as coexistence state of $\Lambda(1405)$ and $a_0(980)$ clusters, and $\bar{K}$ is a constituent of both $\Lambda(1405)$ and $a_0(980)$ at the same time. Consequently, the binding energy and the width of the $K\bar{K}N$ state is almost the sum of those in $\Lambda(1405)$ and $a_0(980)$,

and the dominant decay modes are $\pi\Sigma K$ from the $\Lambda(1405)$ decay and $\pi\eta N$ from the $a_0(980)$ decay. The decays to $\pi\Lambda K$ and $\pi\pi N$ channels are suppressed. We also have found that the root-mean-square radius of the $K\bar{K}N$ state is as larger as 1.7 fm and the inter-hadron distances are larger than 2 fm. These values are comparable to, or even larger than, the radius of ^{4}He and typical nucleon-nucleon distances in nuclei. Therefore, the $K\bar{K}N$ system more spatially extends than typical baryon resonances. These features are caused by the weak binding of the three hadrons, for which the KN repulsive interaction plays an important role.

Our finding that the $\Lambda(1405)$ keeps its properties in few-body systems motivates the $\Lambda(1405)$ doorway picture for the $\bar{K}$ absorption into nucleus discussed in Ref. [26], in which the non-mesonic decay of kaonic nuclei is investigated under the assumption that the $\bar{K}$ absorption takes place through the $\Lambda(1405)$.

For the experimental confirmation of the new N^* resonance discussed here, a recent paper [27, 28] discusses a relation of the new N^* state with the bump structure in $\gamma p \to K^+\Lambda$ observed in recent experiments [29], and proposes other experimental consequences in different reactions.

Although the obtained $K\bar{K}N$ state is located below the thresholds of $\Lambda(1405) + K$, $f_0(980) + N$ and $a_0(980) + N$, there could be a chance to access the $K\bar{K}N$ state energetically by observing the $\Lambda(1405) + K$, $f_0(980) + N$ and $a_0(980) + N$ channels in the final states, because these resonances have as large widths as the $K\bar{K}N$ state. Since, as we have shown, the $K\bar{K}N$ state has the large $\Lambda(1405) + K$ component, the $K\bar{K}N$ state could be confirmed in its decay to $\Lambda(1405) + K$ by taking coincidence of the $\Lambda(1405)$ out of the invariant mass of $\pi\Sigma$ and the three-body invariant mass of the $\pi\Sigma K$ decay. It is also interesting point that the $K\bar{K}N$ state can be a doorway state of the $\Lambda(1405)$ production. This means that presence of the three-body N^* resonance at 1.9 GeV could affect spectrum of $\Lambda(1405)$ production. Thus, this N^* would explain the strong energy dependence of the $\Lambda(1405)$ production observed in the $\gamma p \to K^+\pi^\pm\Sigma^\mp$ reaction at SPring8 [30].

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